The MODIS Land Products: Surface Reflectance and BRDF/Albedo - Data Sets, Algorithms, and Examples

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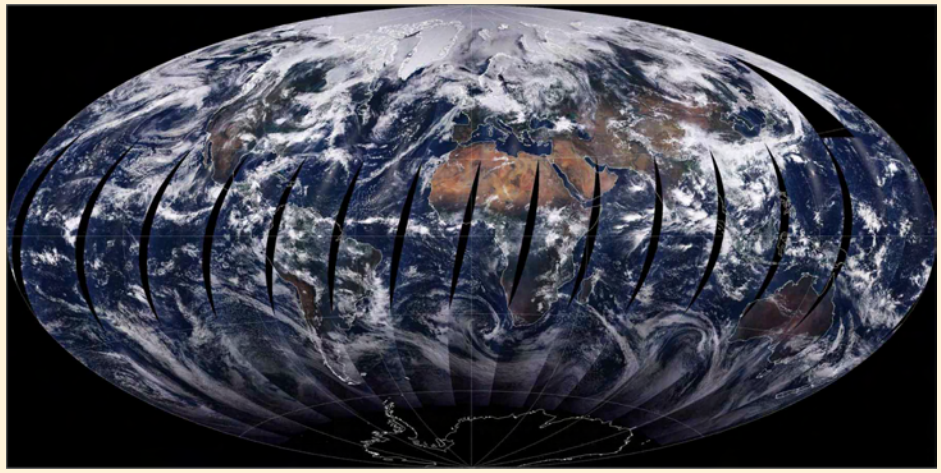
MODIS Data Workshop
Sede Boker, Israel
3-6 November 2008



MODIS true-color daily composite

Outline

- MODIS Land Collection 5
- Surface reflectance product
- BRDF/Albedo product
- “Spatially Complete” (interpolated) Albedo datasets

When it comes to using remote sensing data (or any data), a little bit of knowledge can be a dangerous thing!

– ask questions

Overview of MODIS Land Products

Energy Balance Product Suite

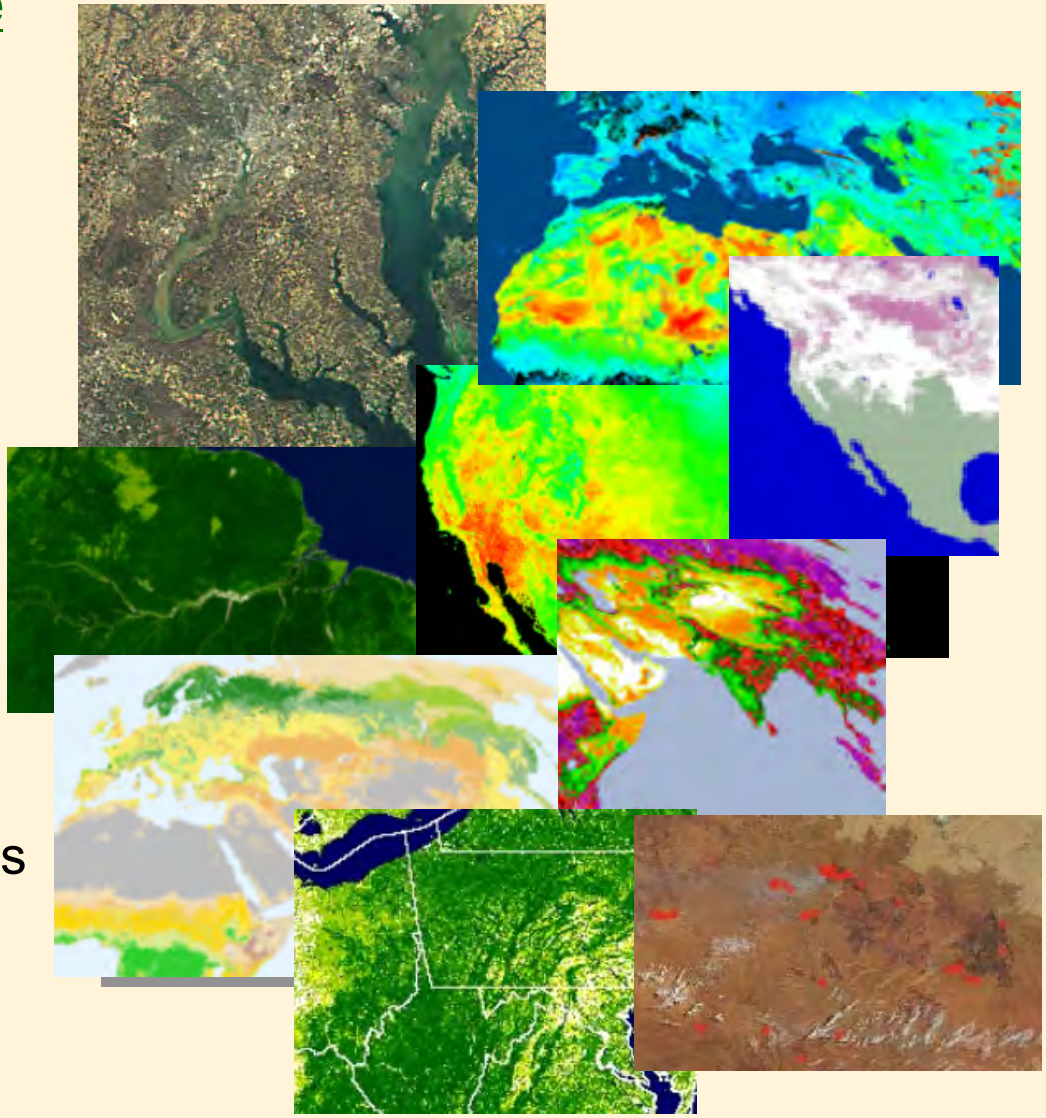
- Surface Reflectance
- BRDF/Albedo
- Land Surface Temperature, Emissivity
- Snow/Sea-ice Cover

Vegetation Parameters Suite

- Vegetation Indices
- LAI/FPAR
- GPP/NPP

Land Cover/Land Use Suite

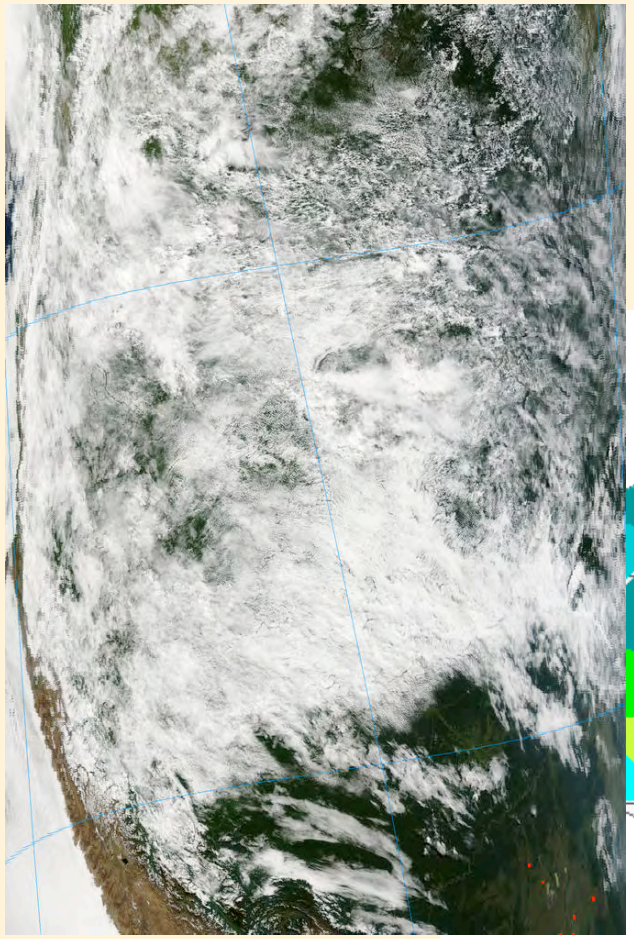
- Land Cover/Vegetation Dynamics
- Vegetation Continuous Fields
- Vegetation Cover Change
- Fire and Burned Area

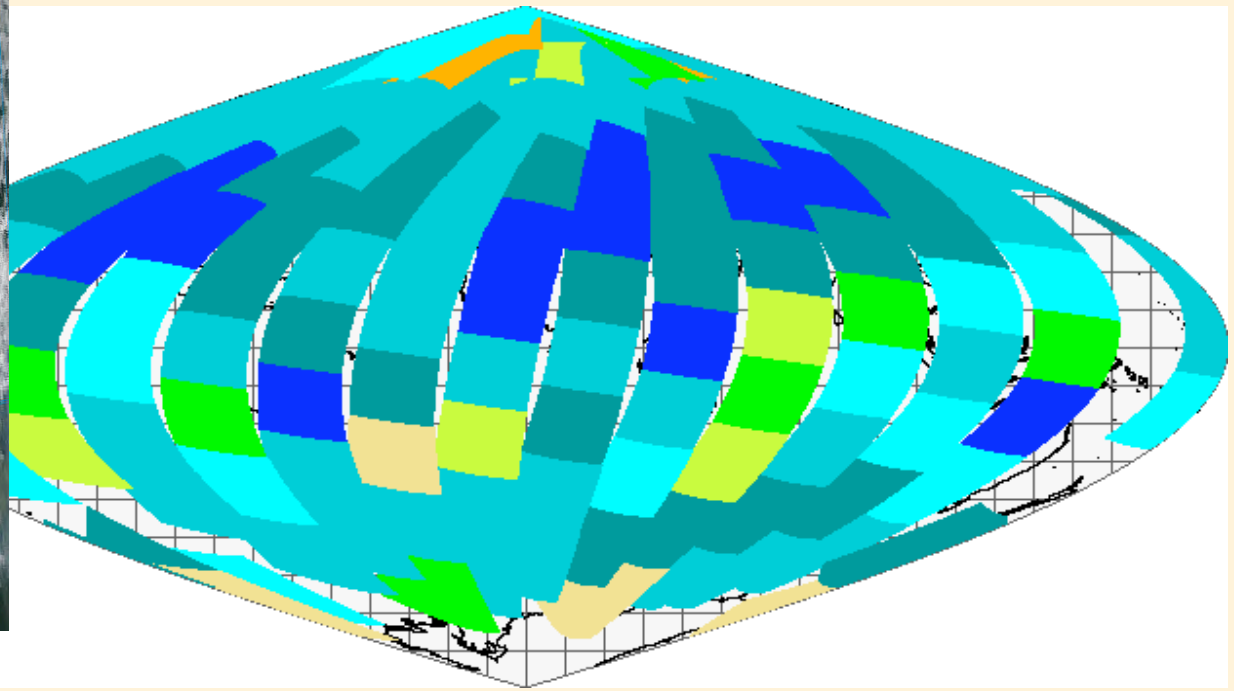


From R. Wolfe

Level-2 Land Products

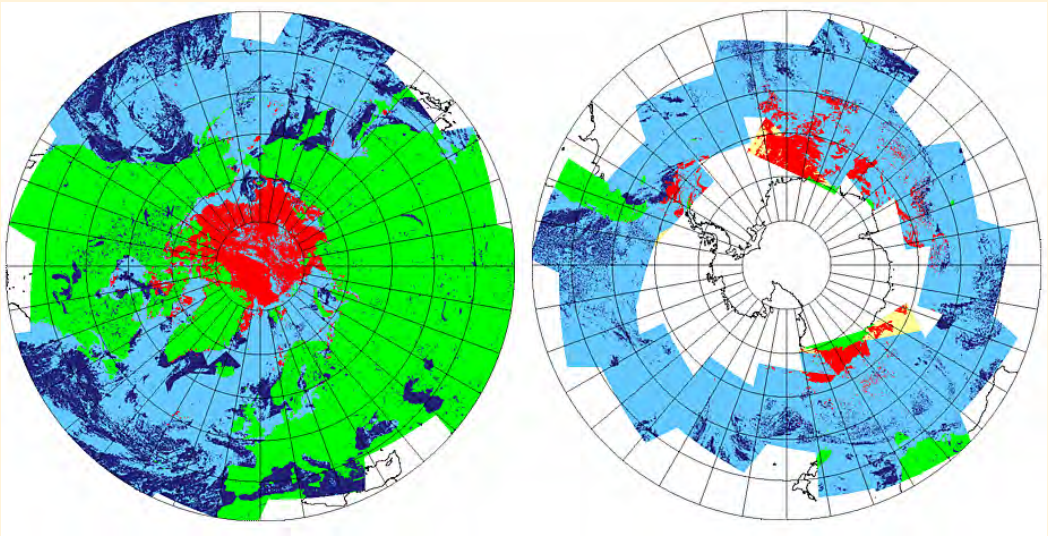
- Retrieved geophysical parameters at the same location and in the same format as the MODIS Level 1 instrument data
  - 288 granules/day; 5 min.; approx. 2340 x 2030 km
  - 250m, 500m and 1km nadir resolutions





From R. Wolfe

Level-2G, 3, and 4 Land Products

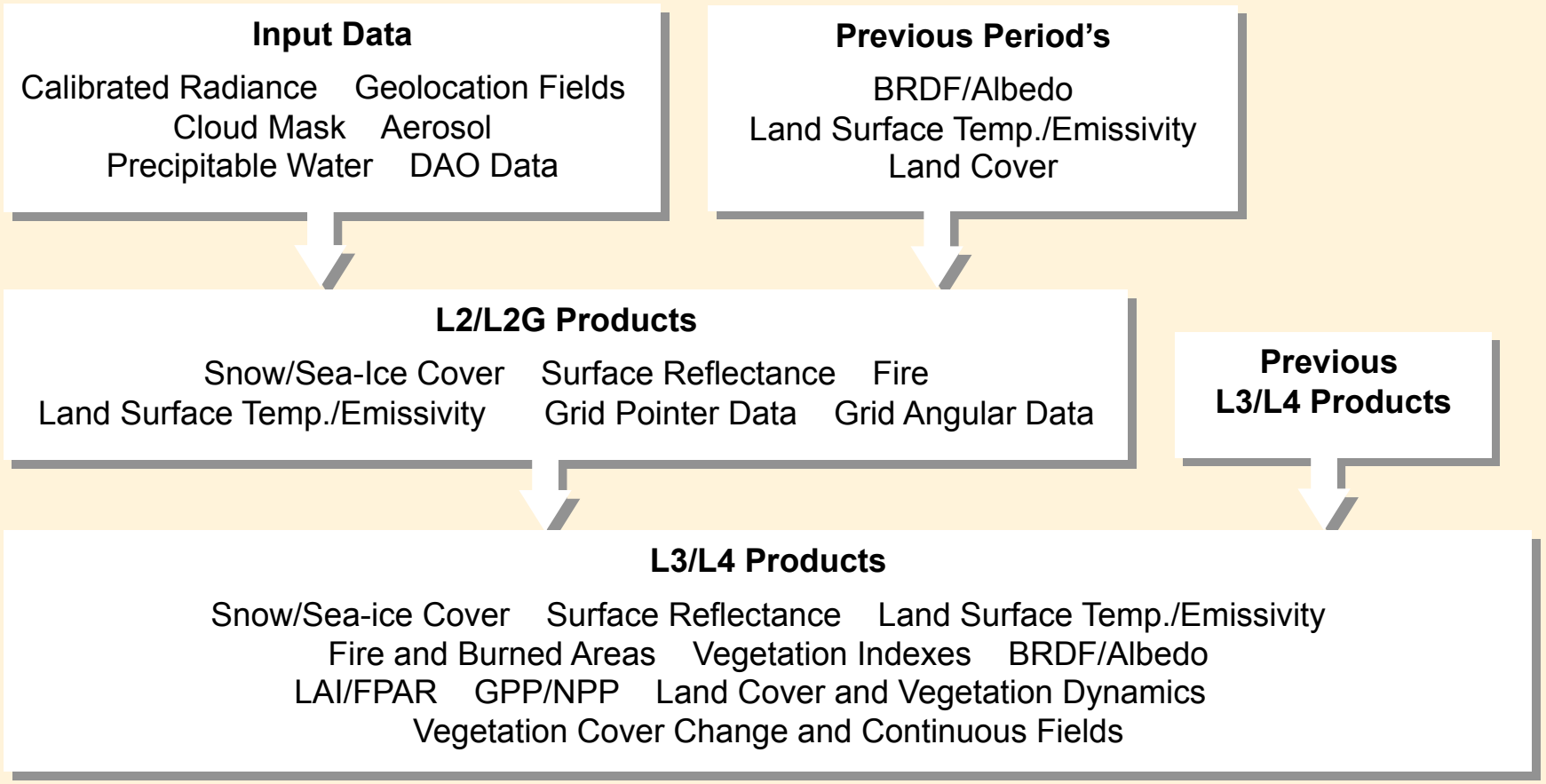


- Level 2G/3: earth-gridded geophysical parameters
- Level 4: earth-gridded model outputs
- Daily, 8-day, 16-day, 32-day, monthly and yearly products
- 10º x 10º Tiles
- Sinusoidal (equatorial); 7.5, 15 and 30 arcsec. resolution (roughly 250m, 500m and 1 km)
- LAEA (sea-ice products, polar projection)

Lambert Azimuthal Equal Area (LAEA)

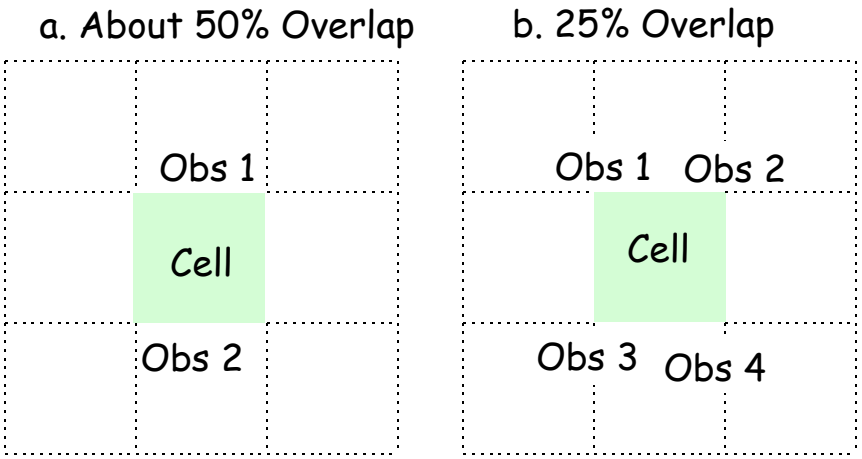
From R. Wolfe

Land Algorithm Dependency



From R. Wolfe

Land Level-2G (Multiple Observations) – Simple Case



Multiple observations covering a single grid cell:

a. about 50% of overlap distributed into two observations
b. 25% of overlap distributed over four observations.

Distribution of coverage for each of the observation with the largest intersection with a cell

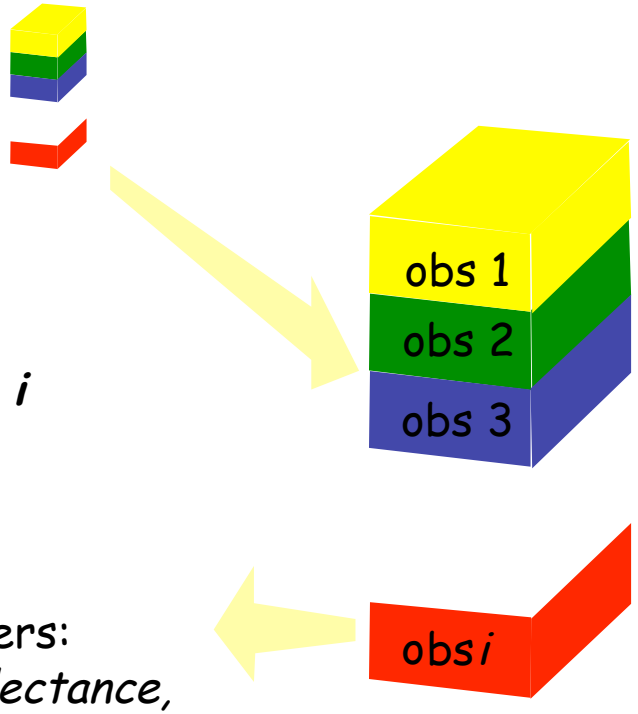
Observation Coverage (%)	Percent of Observations
75 to 100	16
50 to 75	57
25 to 50	37
0 to 25	0

Observations and grid cell are the same size and have the same orientation

From R. Wolfe

Land Level-2G Format

L2G product with same spatial dimensions as corresponding L3 tile



Stack of observations per output grid cell

Observation *i*

Pointer information:
- *granule pointer,*
- *line, sample, etc.*

Geophysical parameters:
- e.g., *land surf. reflectance,*
- *thermal anomalies, etc.*

Viewing geometry:
- *view zenith,*
- *solar zenith, etc.*

From R. Wolfe

MODIS Land Collection 5

• Processing of the MODIS Land Collection 5 began in September of 2006 starting with the Terra (from first data collected in February of 2000). The full reprocessing of MODIS Land data was completed in May of 2008.

• Collection 5 processing of current MODIS data, or forward processing, began at the beginning of 2007.

MODIS Land Collection 5 Change Summary

- Used improved Land/Water mask and new Land Cover map based on 3 years of Collection 4 data
- Refined surface reflectance by adopting a dynamic aerosol model in atmospheric correction
- Reduced size and complexity of daily surface reflectance products
- Improved quality of the Land Surface Temperature by revising the day/night algorithm and improving the detection and filtering of cloud contaminated observations
- Increased resolution of BRDF/Albedo products to 500m
- Refined LAI/FPAR LUTs to improve numerical accuracy of the radiative transfer simulations
- Added fractional snow algorithm in the snow product
- Burned area product added
- Improved ancillary data interpolation to remove artifacts in the NPP product
- Reduced size of all Land products through HDF internal compression

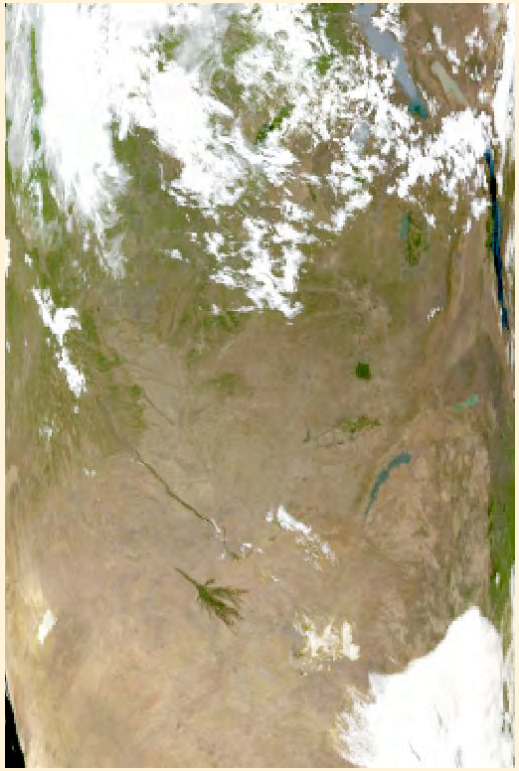
From R. Wolfe

Surface Reflectance Product - Example

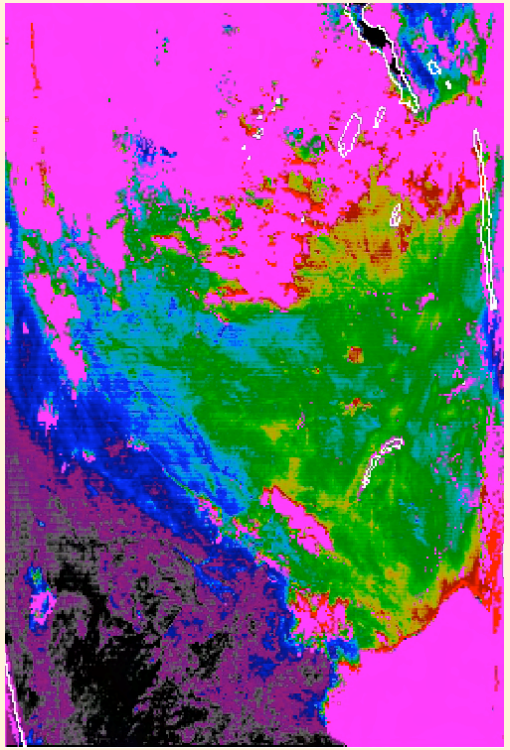
(smoke aerosol, E. Vermote et al.)

MODIS Granule over South Africa (Sept,13,2001, 8:45 to 8:50 GMT)

RGB no correction for aerosol effect



RGB surface reflectance (corrected for aerosol)



Corresponding aerosol optical thickness at 670nm (0 black, 1.0 and above red) linear rainbow scale. Clouds are in magenta, water bodies are outlined in white.

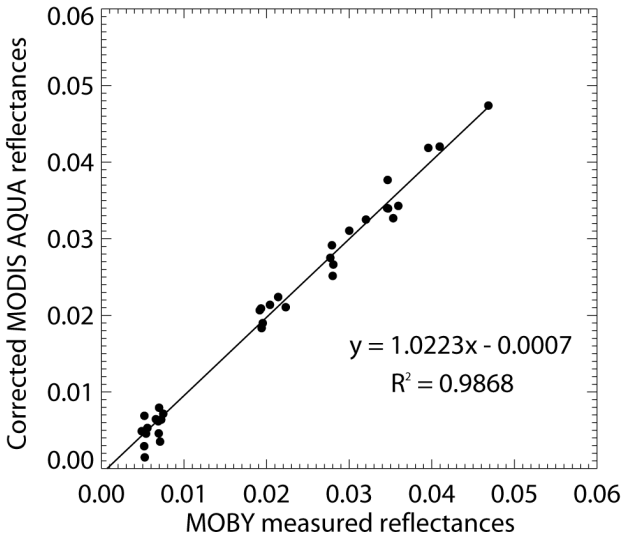
Surface Reflectance Product - Approach

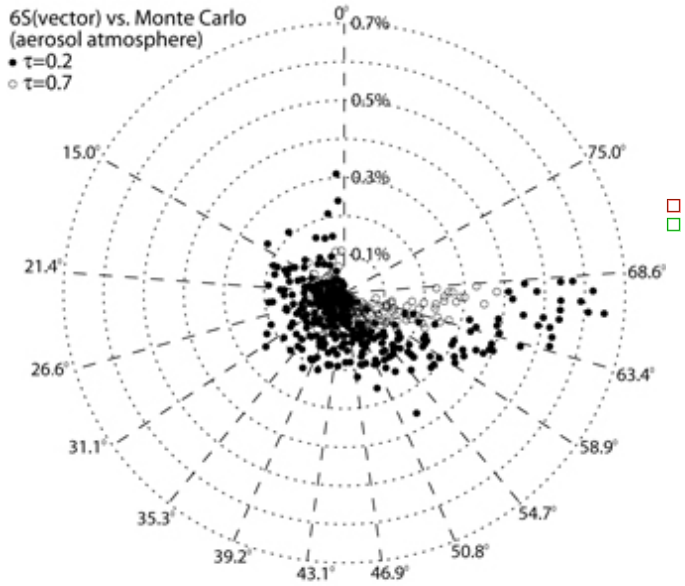
(E. Vermote et al.)

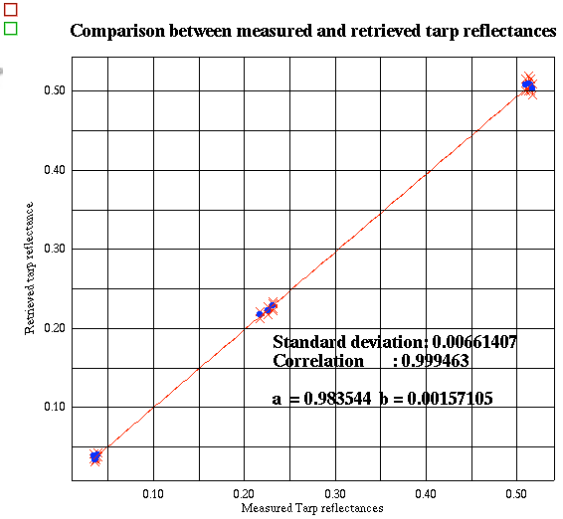
- Atmospheric correction consistent with the MODIS and NPP approach, ensuring consistent reflectance data across resolutions based on rigorous radiative transfer

  http://6s.ltdri.org

  http://rtcodes.ltdri.org/







Surface Reflectance Product – Approach

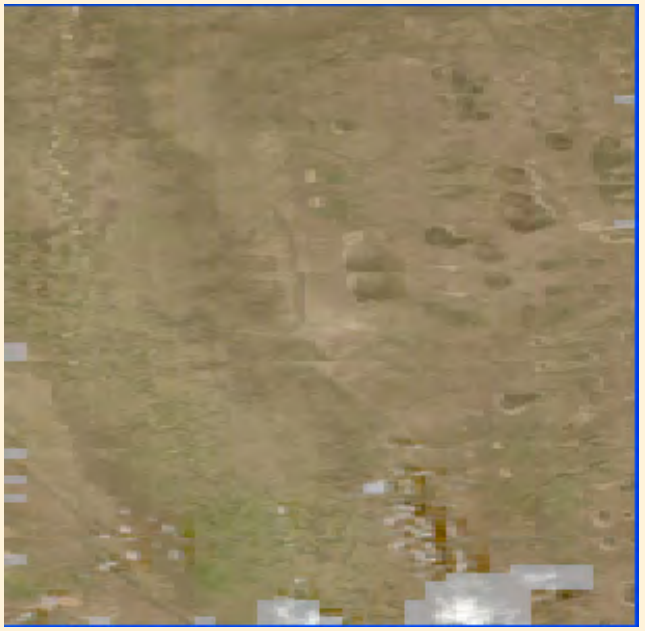
- **1)** ***Aerosol characteristics (vertical profile (optional), aerosol optical thickness (AOT), single scattering albedo (SSA), particle size distribution, and refractive indices****)*. AOT is retrieved from MODIS data with the help of the internal aerosol inversion algorithm. SSA, size distribution and refractive indices are the parameters of one of four pre-assigned aerosol models, which is also selected by the internal aerosol algorithm. The vertical profile is in most cases assumed to be exponential. AOT needs to be retrieved at the spatial resolution of 1 km due to its high spatial variability, while the other aerosol parameters can be retrieved at a coarser resolution with little loss of accuracy. Uncertainties on AOT retrievals depend on atmospheric conditions. The goal is to retrieve AOT with an accuracy of 0.01, in correlation with the AERONET accuracy requirements.
- **2)** ***Atmospheric pressure****.* This parameter is obtained from the combination of the 1-degree resolution 6-hr time step Numerical Weather Prediction Model (NWP) provided by the National Center for Environmental Prediction Global Data Assimilation System (NCEP GDAS) and the 1-km resolution Digital Elevation Model (DEM) provided by the US Geological Survey (USGS). The DEM is used to map surface pressure data at a higher resolution within each meteorological data grid cell. The accuracy of the final pressure is assumed to be 10 mbar
- **3)** ***Ozone concentration****.* This parameter is extracted with the accuracy of ±0.02 cm·atm from experimental measurements performed by a UV ozone sounder (e.g., NASA's Total Ozone Mapping Spectrometer (TOMS)) at a coarse spatial (1 deg.) and temporal (1 day) resolution.
- **4)** ***Column-integrated water vapor content****.* This content is derived from the MODIS near-infrared band 18 (931-941 nm) and 19 (915-965 nm) at 1 km spatial resolution using the two-band ratio described by *Gao and Kaufman* [2003]. Such an approach determines the instantaneous water vapor content at the time of acquisition with an accuracy of 5-10%. Meteorological data from NCEP GDAS are used when required MODIS data are not available.

Surface Reflectance Product – Aerosol Inversion over Mongu, Zambia

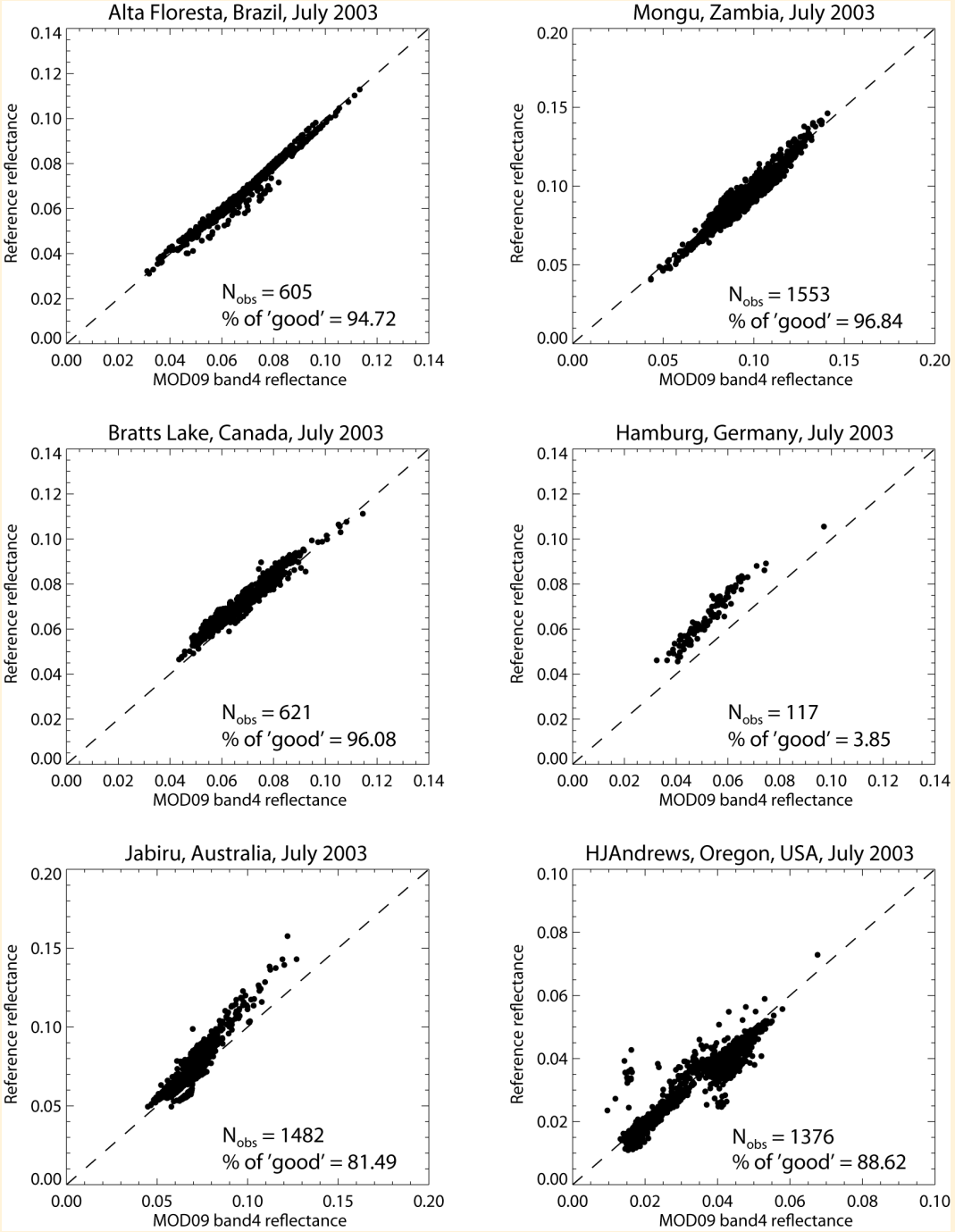
Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.982	0.019	2.183	0.001	14

MOD09				
avg AOT	std AOT	avg WV	std WV	nb obs
0.990	0.049	1.873	0.040	0

AOT= 0.927
(7 x 7km)
Model residual:
SLA: 0.00567
SHA: 0.00433
UP: 0.00436
UC: 0.00523



Evaluation over AERONET Sites (E. Vermote)



Surface Reflectance C5 Changes

(E. Vermote et al.)

1. Land Surface Reflectance (PGEs 11 and 21)

• Reduce striping in the SWIR bands using Liam Gumley's algorithm to reduce noise in the retrieved aerosol optical thickness and subsequently in the surface reflectance.
• Refine the internal masks (cloud and cloud shadow masks) and expand the mask to include flagging of pixels adjacent to clouds where aerosol optical thickness retrieval is disabled.
• Use the new version of 6S with improved polarization handling to create atmospheric correction Look up tables (LUT).
• Modify LUT format to improve the accuracy atmospheric parameters interpolation.
• Use dynamic aerosol models and ocean bands to improve aerosol retrieval and correction over land.
• Refine atmospheric correction - aerosol retrieval and correction in costal area.
• Improve consistency between 250m and 500m composited products.

2. L2G Surface reflectance (PGEs 12, 13, 14, 15)

• Reduce number and size of surface reflectance products to make them more useable size reduced by eliminating most pixels in scan overlap region and by simplifying method of moving between resolutions number of files reduced from 7 to 2 per tile old products kept as internal products to minimize downstream changes archived size reduced from 250 to 120 GB/day (w/o internal compression)
• Create an interim L2G brightness temperature product for use in downstream products such as VCC and Burned Area.

MODIS Albedo Product: BRDF and Albedo

Albedo = net reflected flux/incident flux ("Flux" = W/m^2-μm)

$$A_\lambda(\theta_{sun}) = \mathrm{INT}\{\mu_{sun} I_\lambda^{meas}(\theta_{view}, \theta_{sun}, \Delta\Phi)\, d\mu_{view}\, d\Phi\}$$

where,

I_λ^{meas} = measured spectral reflected radiance (e.g., W/(m^2-μm-sr))

$\mu = \cos(\theta)$, θ = zenith angles

BRDF or BRF: a normalization for the reflected radiance (or intensity), which gives the albedo if the observed radiance was isotropic, i.e.,

$$R_\lambda(\mu_{view}, \mu_{sun}, \Delta\Phi) = \pi I_\lambda^{meas}(\mu_{view}, \mu_{sun}, \Delta\Phi) / \mu_{sun} F_{\lambda,sun}$$

where, $F_{\lambda,sun}$= solar spectral irradiance (e.g., W/(m^2-μm))

BRDF Example – Arctic Tundra

(Arnold et al., 2001)

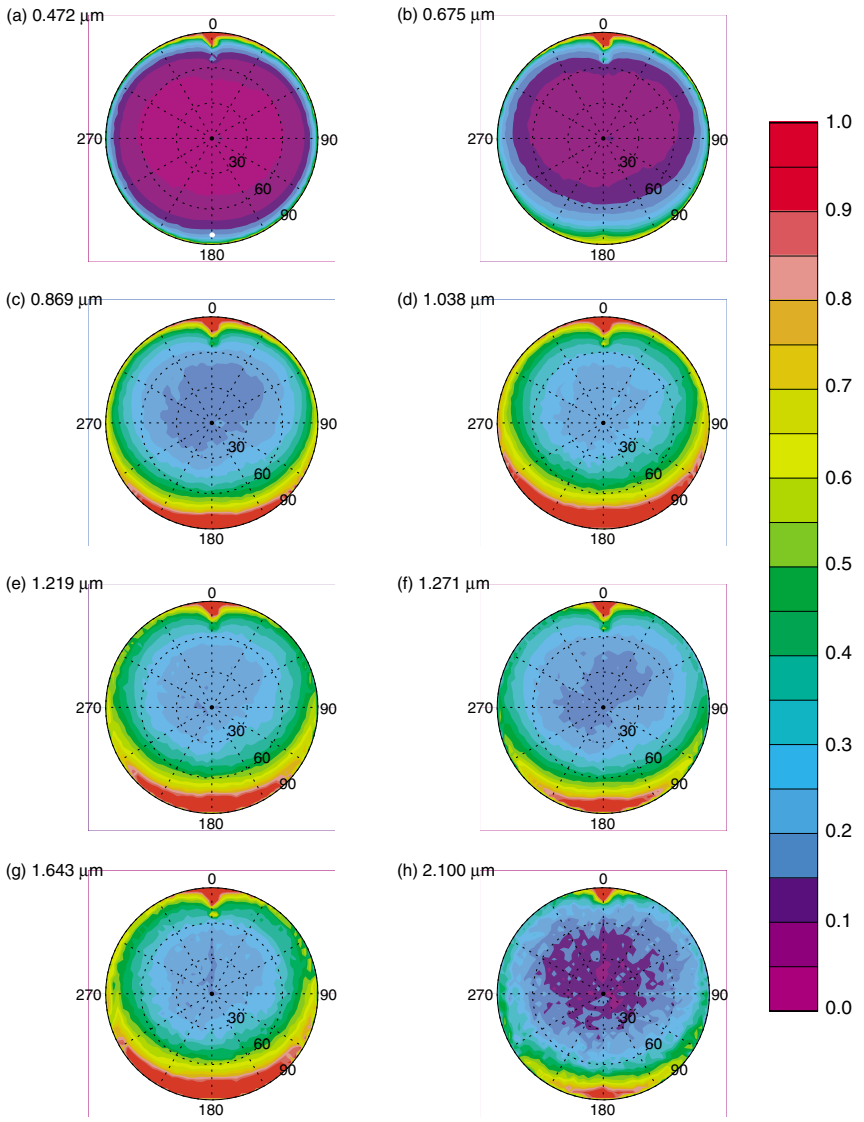
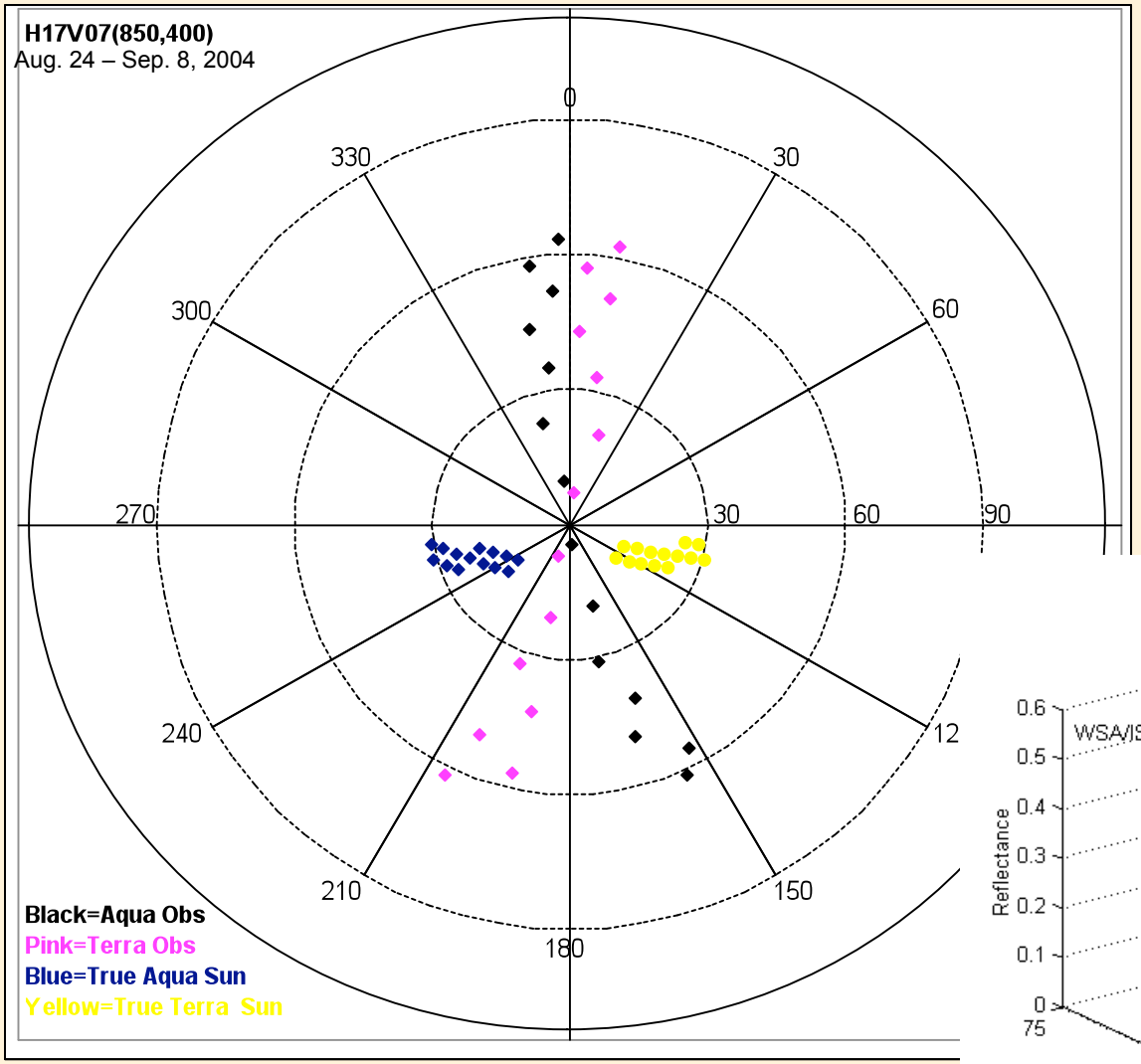
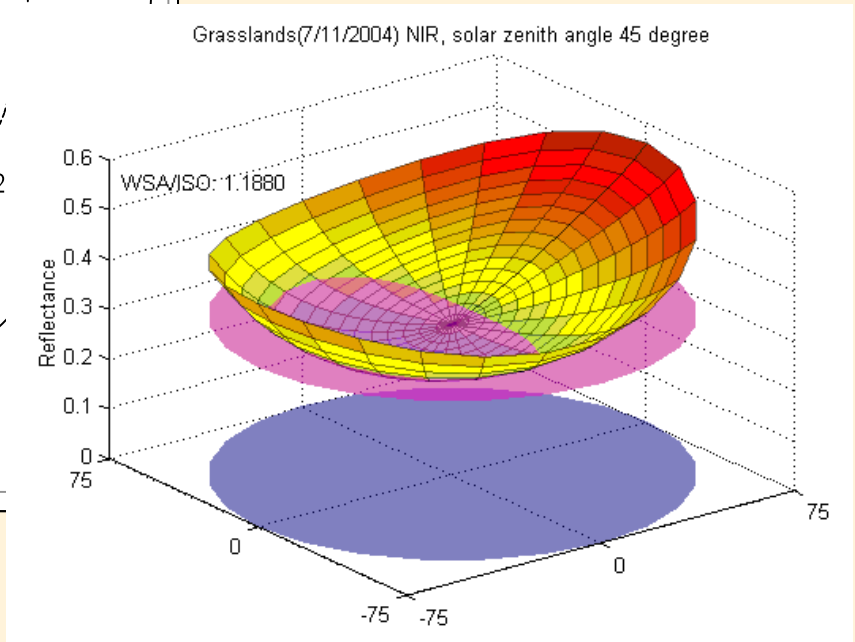


Figure 8. Spectral measurements of surface-atmosphere bidirectional reflectance over snow- free tundra. This case is BRF G on June 12, 1995 during ARMCAS. The location of the anti-solar point at $\theta = 81°$ and $\phi = 180°$ is indicated in figure 8a.

MODIS Anisotropy and Albedo





From C. Schaaf

MODIS Albedo Product (MOD43) - Description

Crytal Schaaf, Alan Strahler, F. Gao, et al.

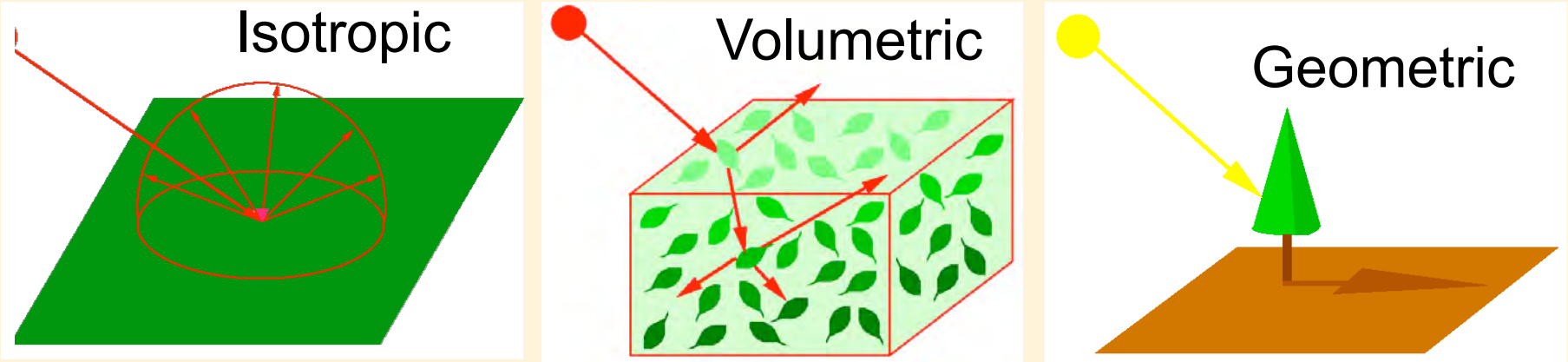
- **Inputs**
  - **Aqua and Terra** cloud-free, atmospherically-corrected, spectral **surface reflectances** (MOD09/MYD09 BRFs) used to sample surface anisotropy over a 16 day period
- **Output**
  - **High quality full inversions** provide well-sampled, best-fit anisotropy models of global land surfaces every 8 days
    - Ross Thick Li Sparse Reciprocal semi-empirical model captures volumetric and geometric-optical (surface scattering and geometric shadow casting) scattering
  - **Lower quality** back-up algorithm provide **magnitude inversions** by coupling available reflectances with *a priori* BRDF database
  - **Majority** condition (**snow/no-snow**) retrieved

From C. Schaaf

Semi-Empirical BRDF Model

$$A_\lambda(\theta_i, \Phi_i; \theta_r, \Phi_r) = f_{iso} + f_{vol}k_{vol} + f_{geo}\,k_{geo}$$

Roujean et al., 1992



*kvol, k*geo are kernels of view and illumination geometry
*f*iso, *f*vol, *f*geo are spectrally dependent weights
Ross-Thick-Li-Sparse Reciprocal model fits and Weights of Determination (WoD) [WoD evaluates the confidence of the retrieval from given angular sampling.]

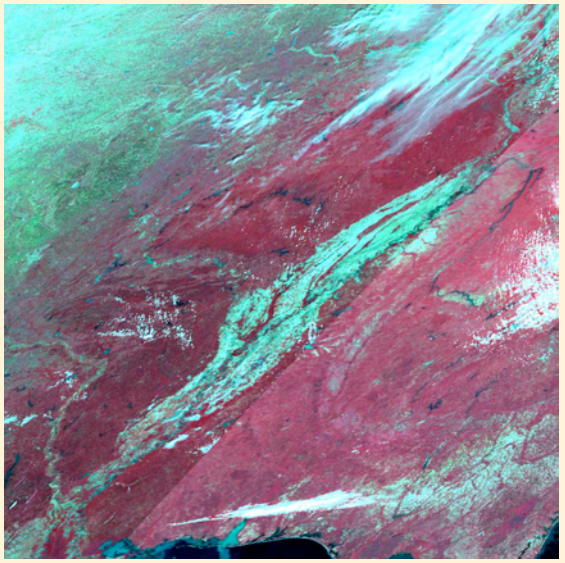
From C. Schaaf

MODIS Albedo Product – Description

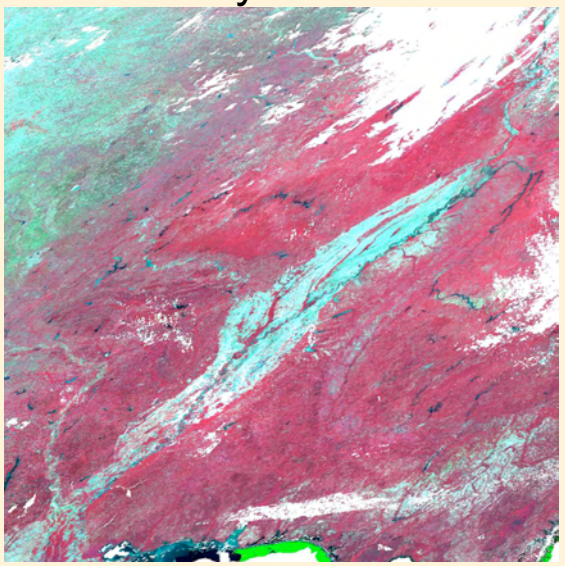
- **BRDF Model parameters (MCD43A1/B1)**
  - Ross-Thick-Li-Sparse model parameters
    - Simple polynomial to estimate albedo
    - Simple shape factors calculated
- **Albedo quantities (MCD43A3/B3)**
  - White-sky albedo or bihemispherical reflectance under isotropic illumination (BHRiso)
  - Black-sky albedo or directional-hemispherical reflectance (DHR) at local solar noon
- **Nadir BRDF-Adjusted Reflectance NBAR (MCD43A4/B4)**
  - View angle corrected surface reflectances
  - Primary input to MODIS land cover, phenology

From C. Schaaf

adjoining swaths



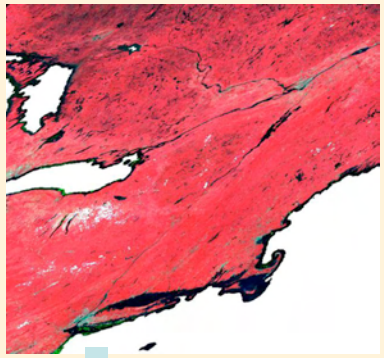
NBAR May 2004

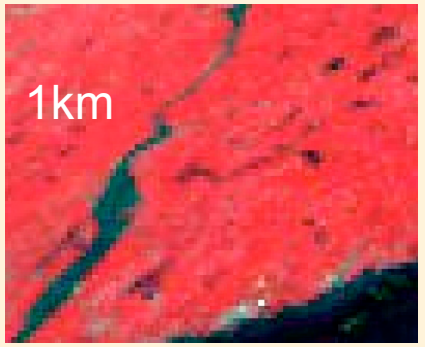


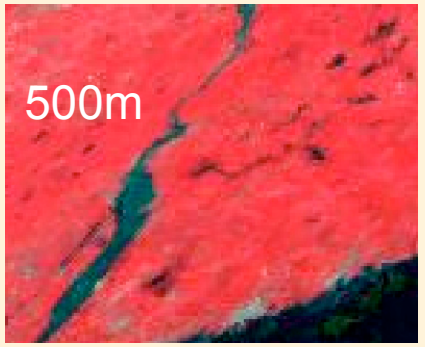
MODIS Albedo Product – Data Sets

- Spectral
  - 7 shortwave bands and three broad bands
- Spatial
  - 500m sinusoidal 10 deg tiles (MCD43A) reported
  - 1km in sinusoidal 10 deg tiles (MCD43B)
  - 0.05deg in global lat/lon (MCD43C) Climate Modeling Grid (CMG)
  - 30arcsec in global lat/lon (MCD43D)

    CMG parameters only
- Temporal
  - Every 8 days based on the last 16 days

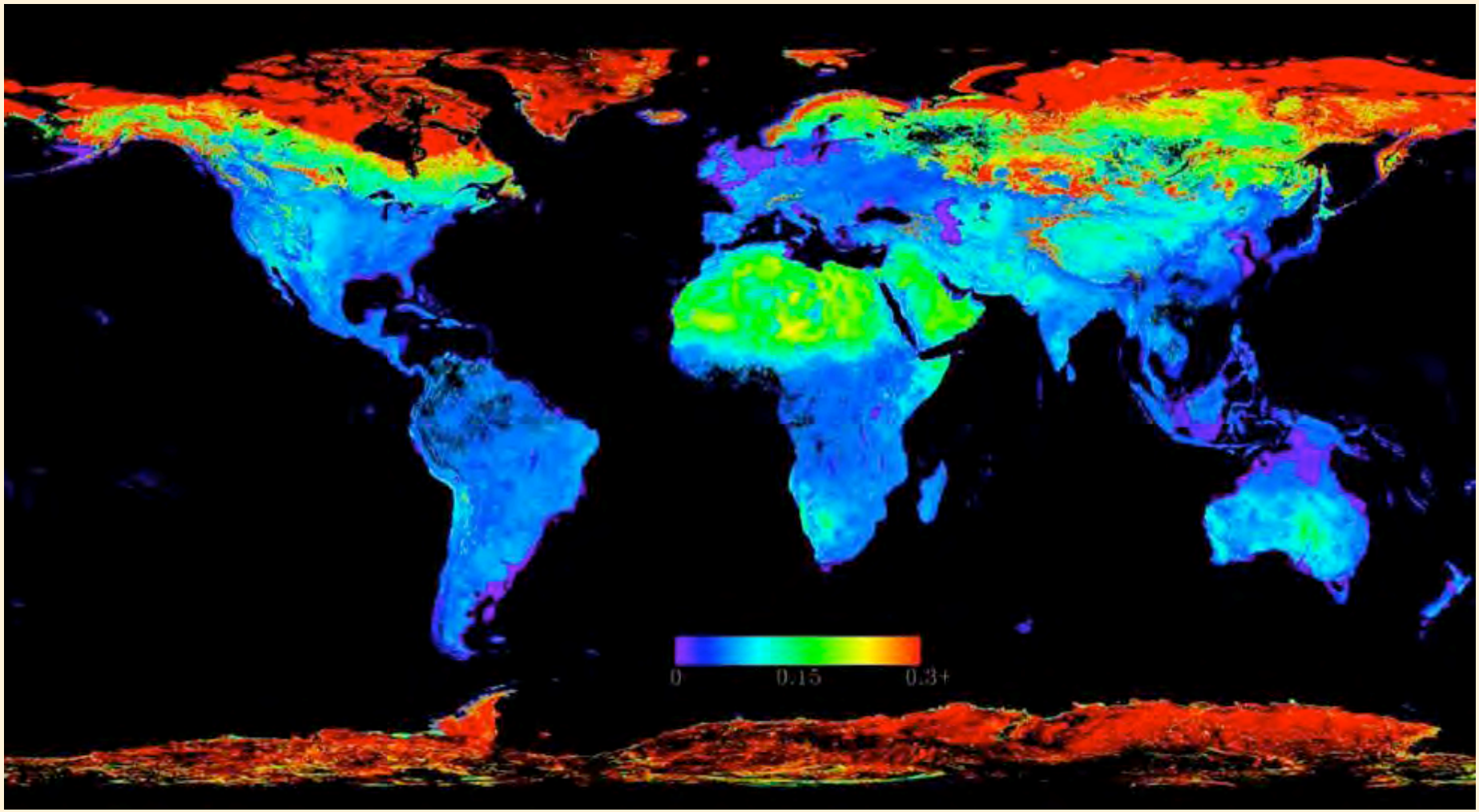






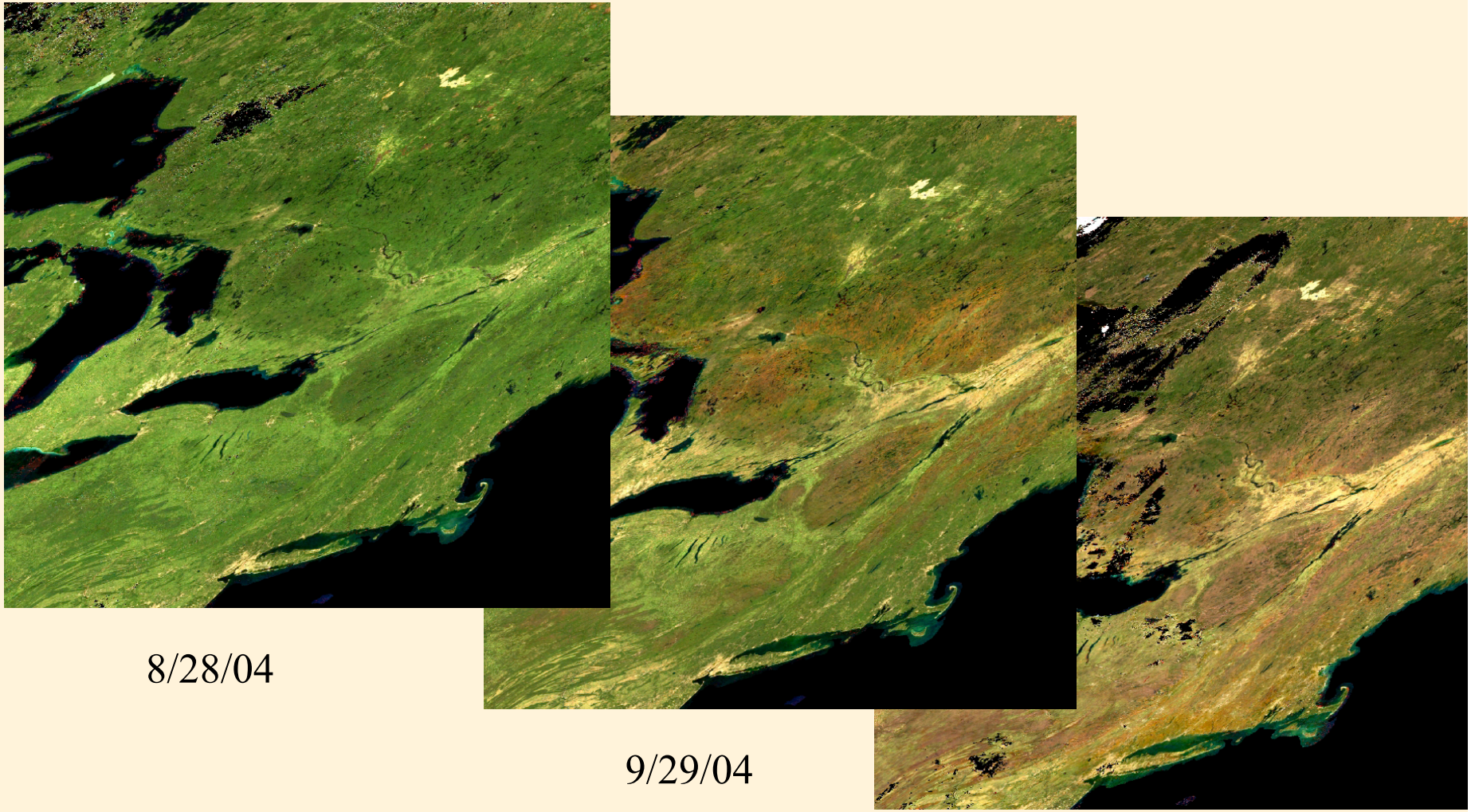
From C. Schaaf

“White Sky” Broadband Albedo, April 2004



From C. Schaaf

New England Foliage



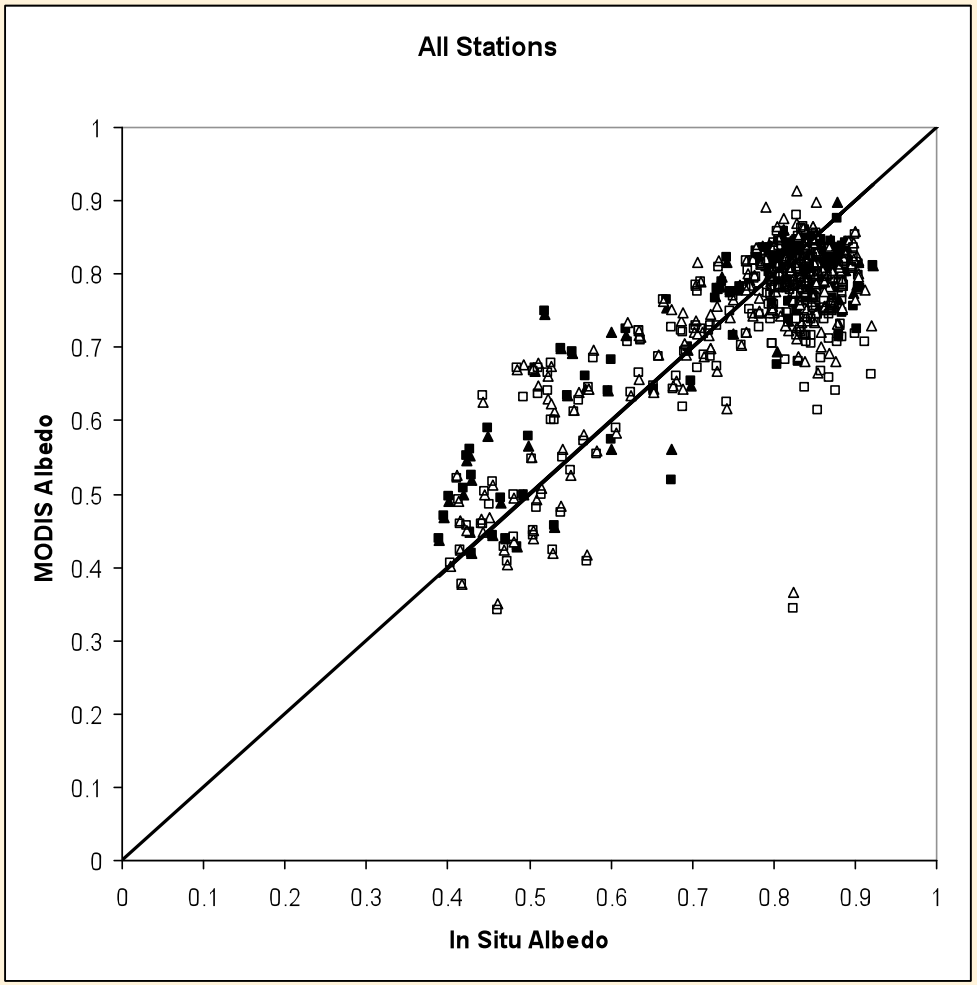
8/28/04

9/29/04

10/15/04

From C. Schaaf

MODIS Albedo over Snow



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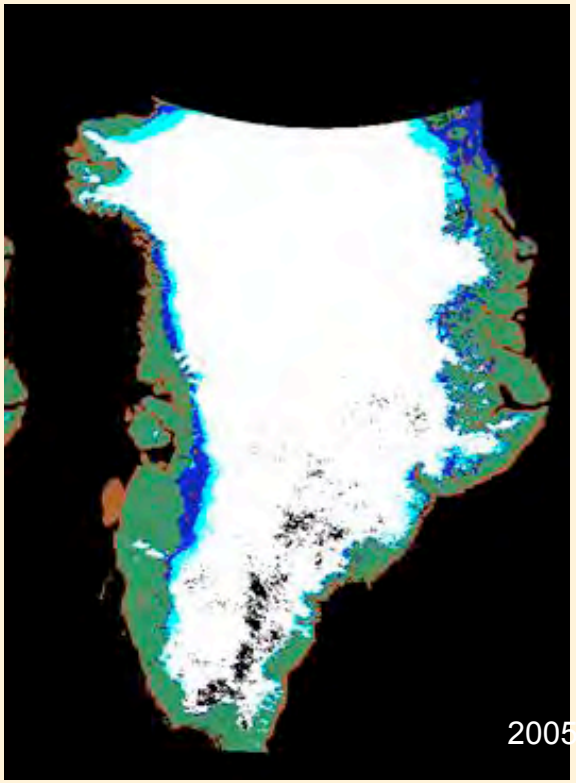


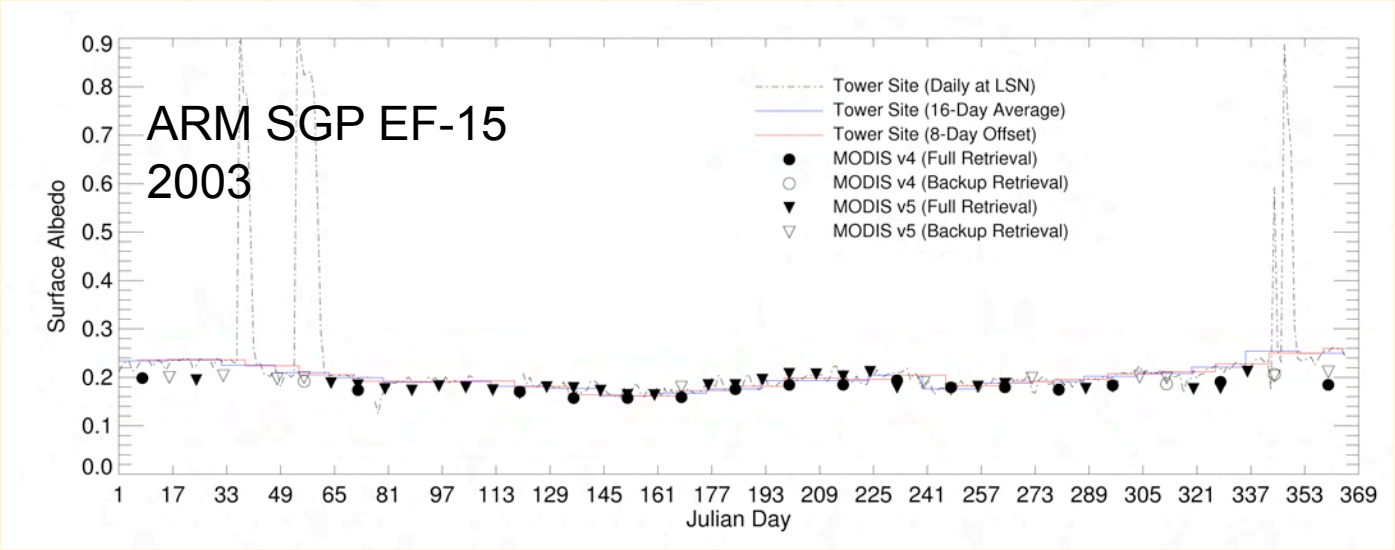
Comparison between MOD43 16-day albedo and 16-day in situ albedo for both **black sky (triangles) and white sky (squares**) albedo for 15 Greenland AWS stations. MODIS albedo from both the “main” (closed symbols) and “backup” (open symbols) algorithm results are shown.

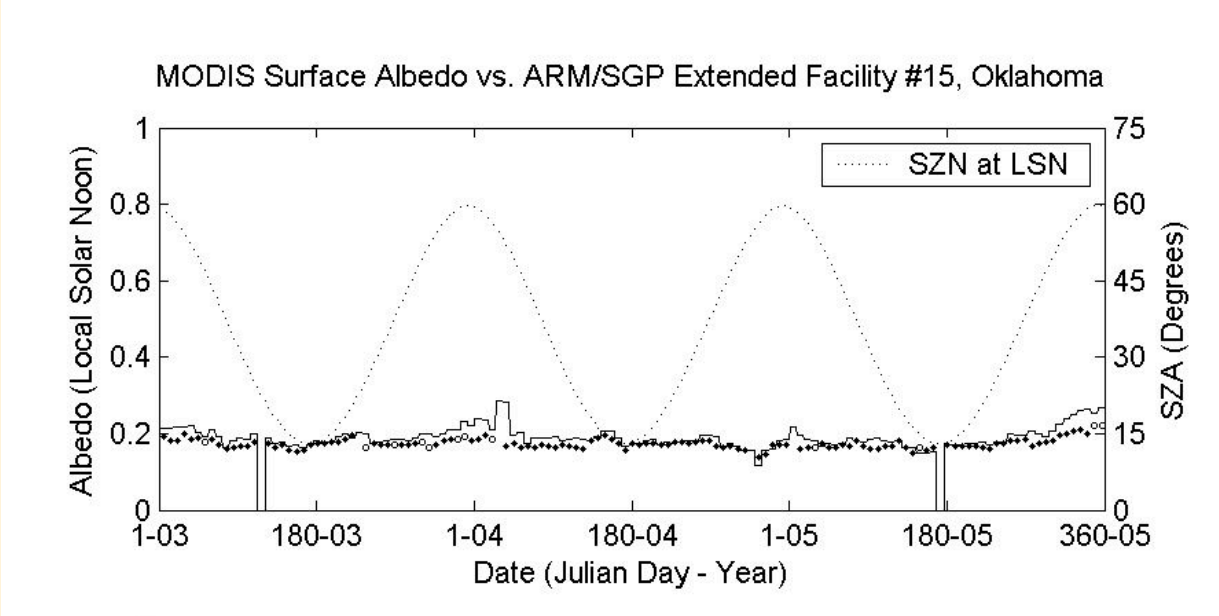
MODIS Albedo Product – Validation

- Albedo relies on **Baseline Surface Radiation Network - BSRN**
  - Calibrated albedometers
  - World Radiation Monitoring Center Alfred Wegener Institute (AWI) in Bremerhaven, Germany
  - http://www.bsrn.awi.de/
  - http://www.gewex.org/bsrn.html
  - Expansion and support of BSRN caliber albedometers required at additional atmospheric, ecological and flux tower sites
- Surface Reflectance, Aerosols, Albedo Products highly dependent on **AERONET** sun photometers for validation
  - http://aeronet.gsfc.nasa.gov/
- CERES/ARM Validation Experiment (CAVE)
  - http://www-cave.larc.nasa.gov/cave/cave2.0/SfcObs.html

From C. Schaaf

Validation at the ARM SGP site





From C. Schaaf

Surface Albedo C5 Changes

(C. Schaaf et al.)

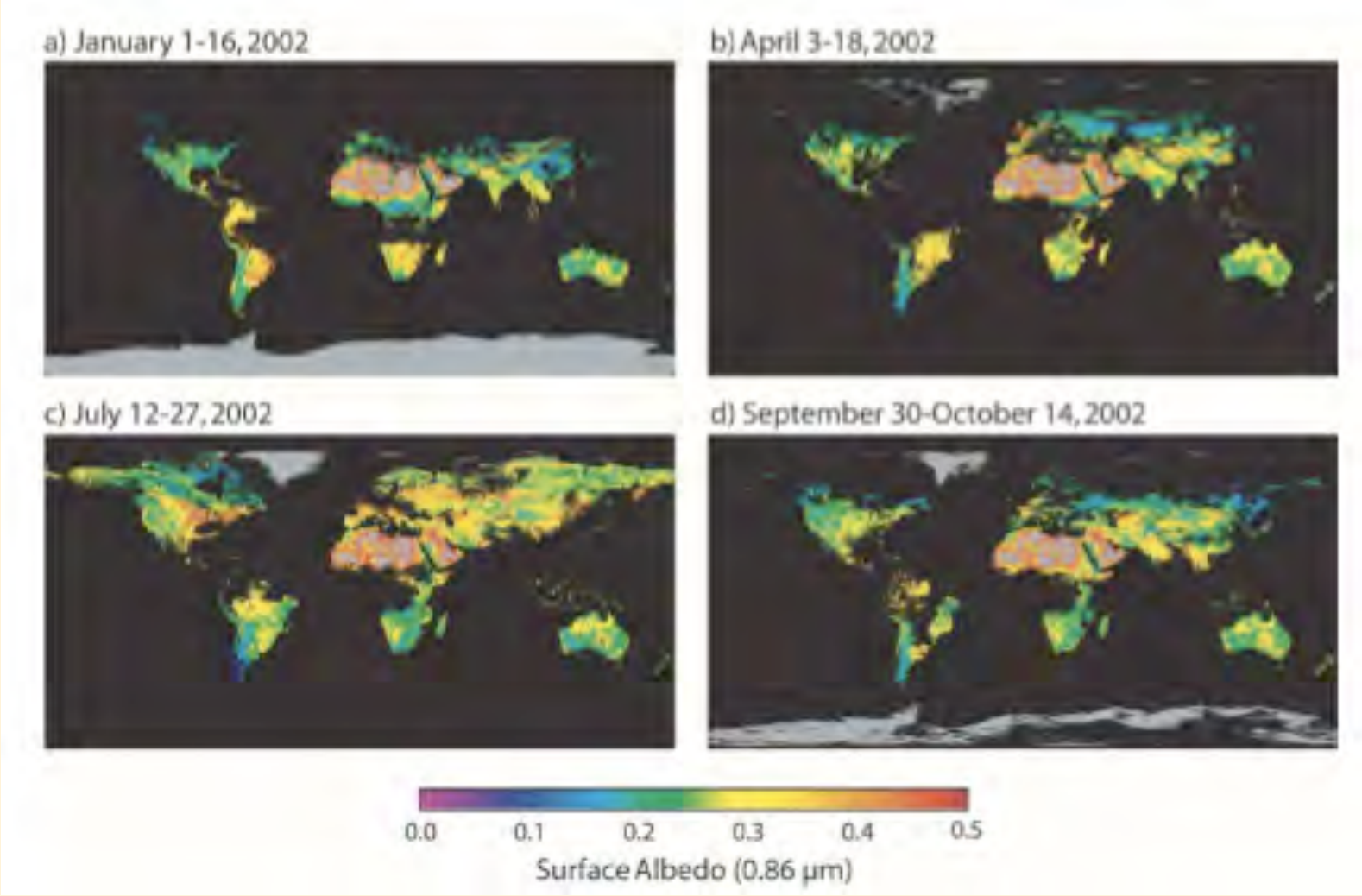
Summary:

- Input: Changed from 1km MODAGAGG files to L2G 500m files
- Output: Changed primary output spatial resolution from 1km to 500m
- Output: 3D/4D SDS output layers have been simplified to 3D/2D structure.
- Output: Second BRDF model was removed
- Output: A simplified QA scheme is used
- Output: All output SDSs are internally compressed
- Algorithm: Obscov weighted mean of observations is used in retrieval
- Algorithm: Local solar noon was changed to the actual number in degrees
- Algorithm: Solar zenith angle for NBAR was changed from mean solar zenith angle to the solar angle at local solar noon time

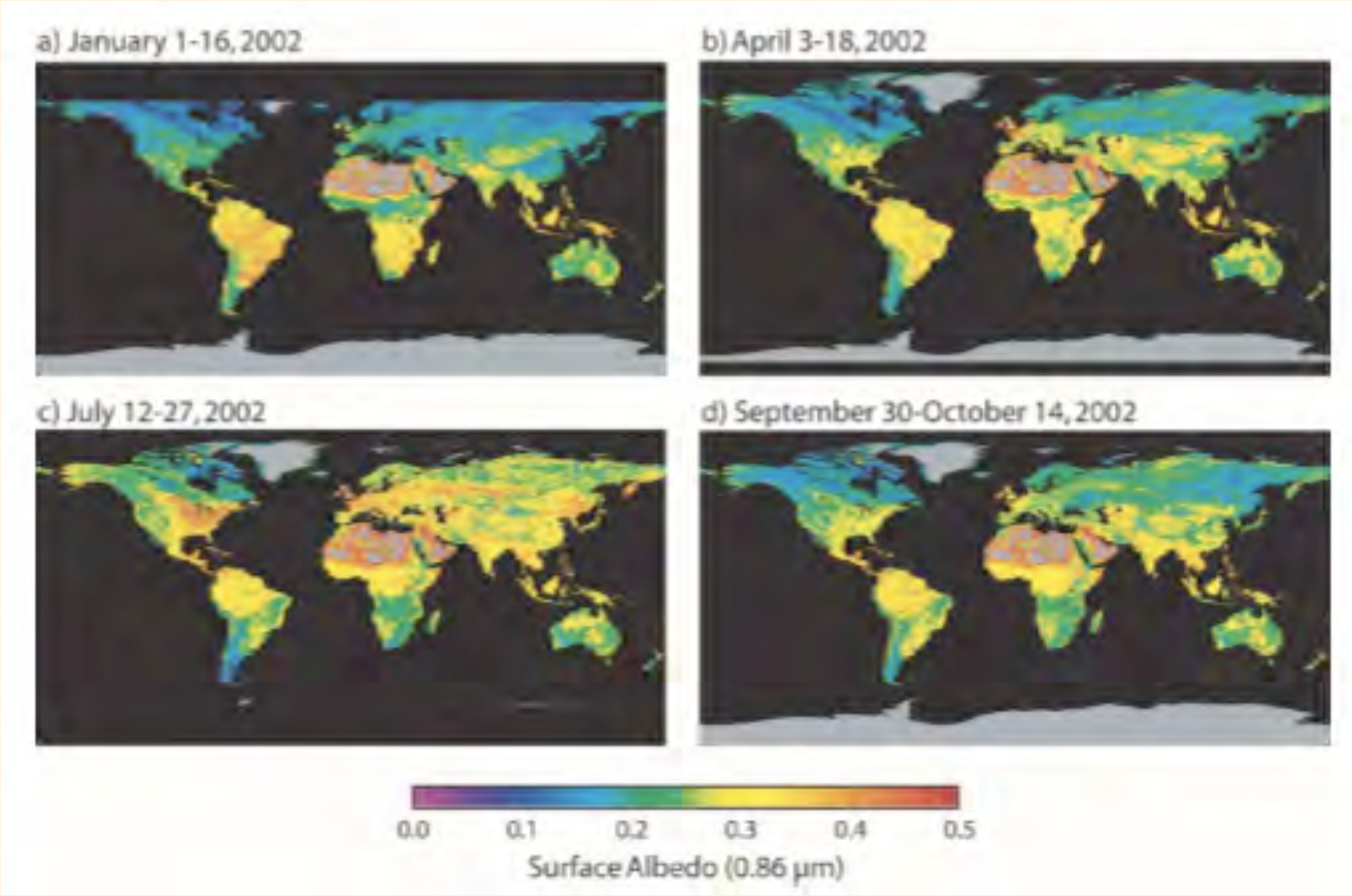
Spatially Complete (Gap-Filled) Surface Albedo Datasets

- Large portions of the globe have a high occurrence of cloud fraction over16 day periods during some times of the years.
- Some users require albedos continuously throughout the year (e.g., modelers, other remote sensing applications).
- Spatial and temporal interpolation scheme is required.
- Project undertaken by Eric Moody et al. in ~2004 to develop a scheme useful for providing continuous albedo boundary conditions for cloud retrievals.
- Terra data set (averaged over the C4 Terra Albedo time record) is available on the MODIS atmosphere team web site.
  - Contains land spectral and broadband albedos for each 16-day period at ~1.7 km resolution (1 arcmin).
  - Snow/ice is an average for all occurrences with binning by sea ice fraction (microwave retrievals from NISE dataset).
- C. Schaaf et al. at Boston Univ. are continuing this effort for Collection 5 Terra/Aqua albedos.

Spatially Complete Surface Albedo Datasets - Before

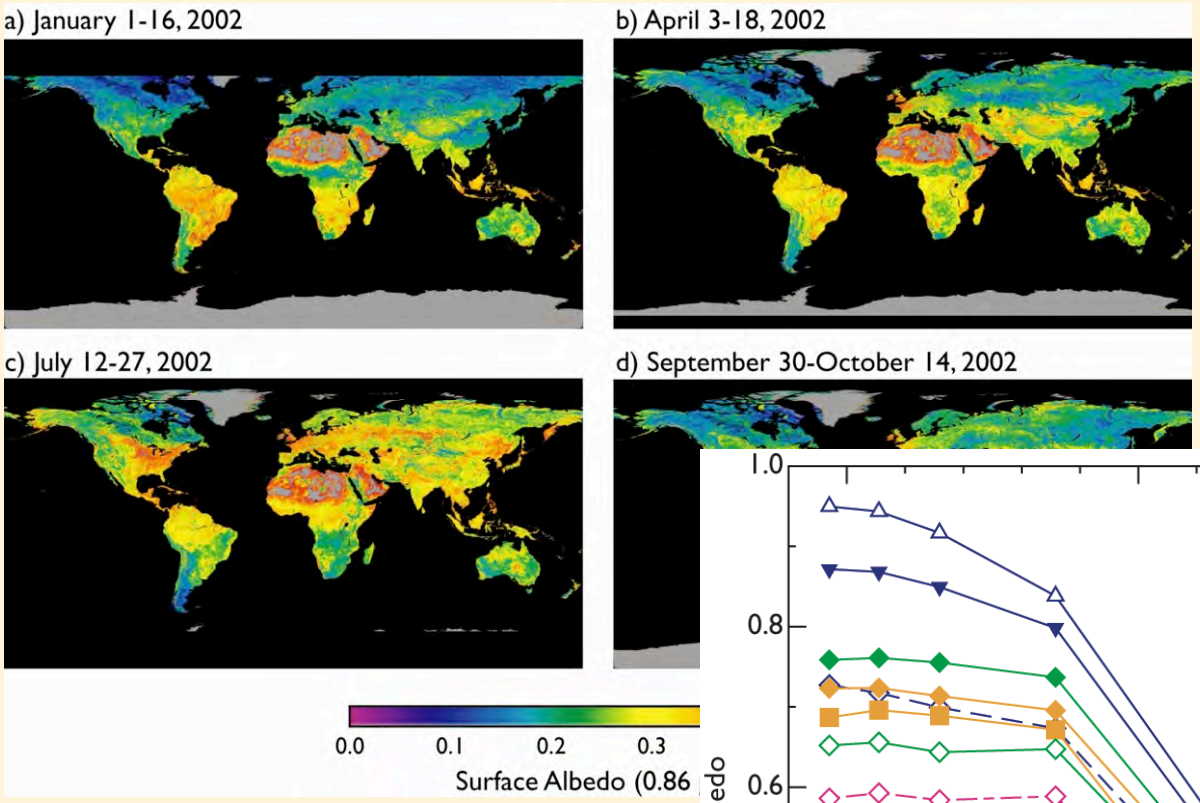


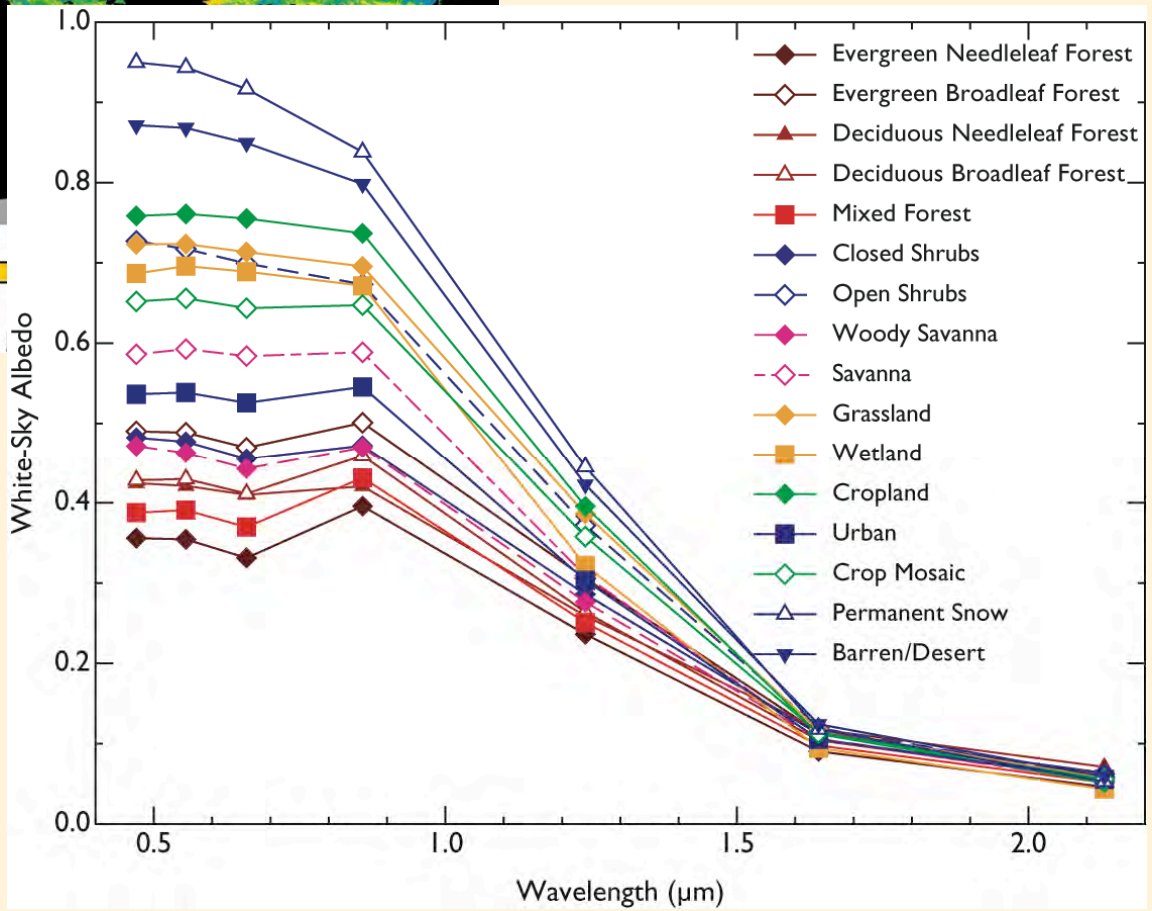
Spatially Complete Surface Albedo Datasets - After



Spectral Surface Albedo Examples

Spatially complete "white-sky" albedo in the MODIS 0.86 μm band for four 16-day periods in 2002 (*after Moody et al. 2005a*).

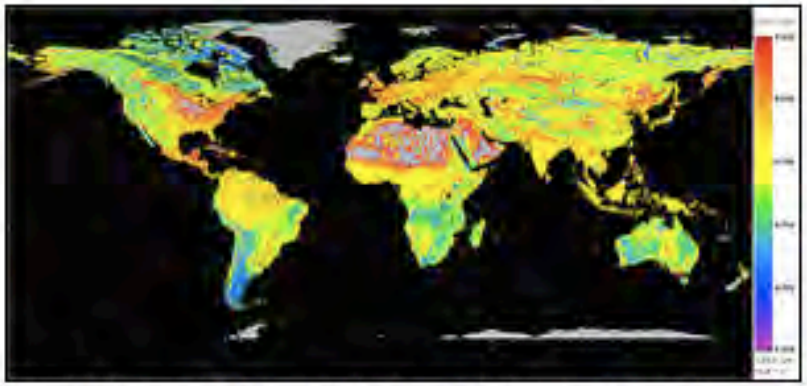




Northern hemisphere multi-year average white-sky spectral snow albedo as a function of selected IGBP ecosystem classifications from 2000-2004 MOD43B3 data (*after Moody et al. 2006b*).

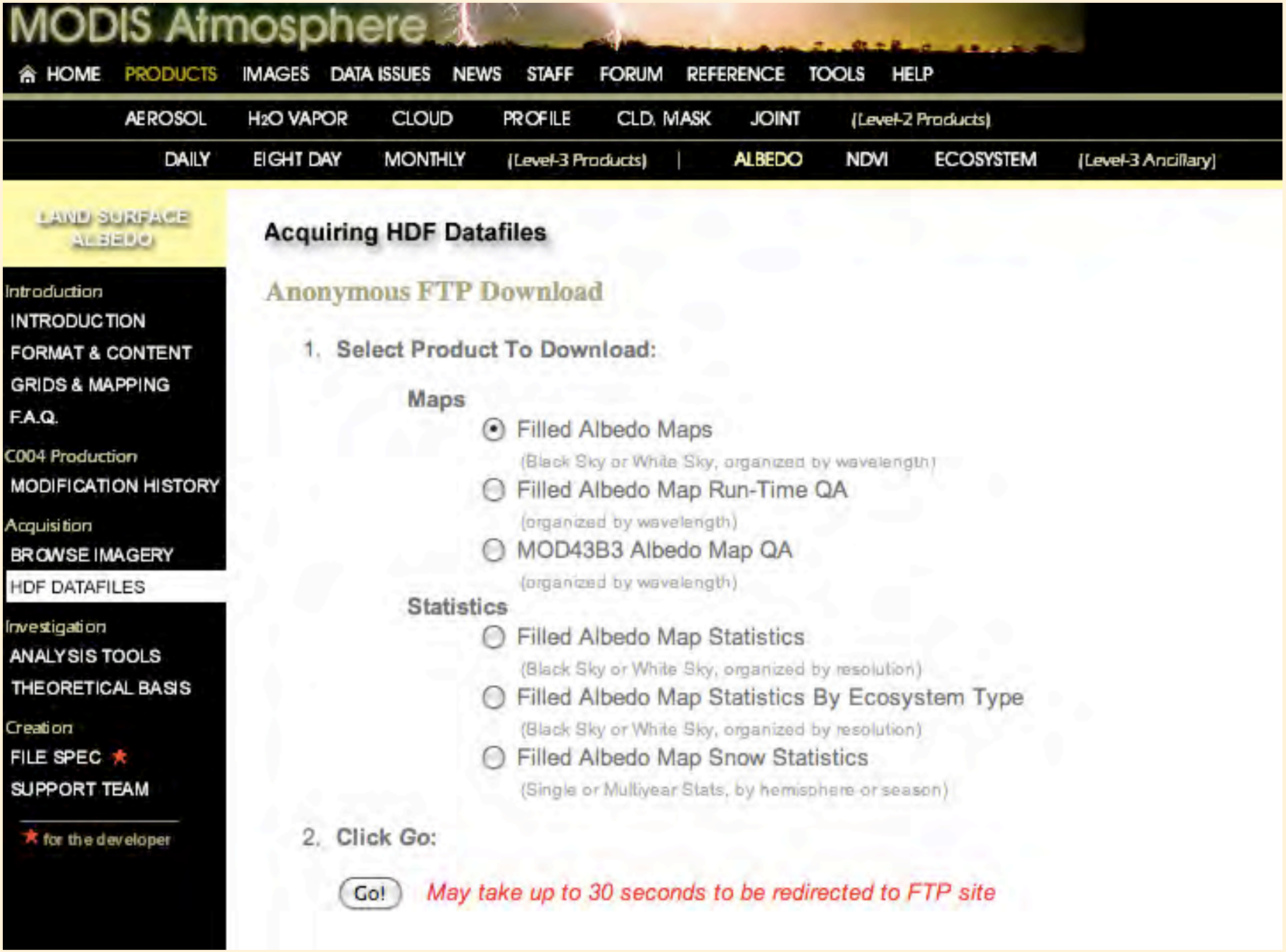
Introduction

Product Description



The Filled Land Surface Albedo Product, which is generated from MOD43B3 (the official Terra/MODIS-derived Land Surface Albedo Product, *website*), is a global data set of spatially complete albedo maps computed for both "white-sky" and "black-sky" at 10 wavelengths (0.47μm, 0.55μm, 0.67μm, 0.86μm, 1.24μm, 2.1μm, 0.3-0.7μm, 0.3-5.0μm, and 0.7-5.0μm) for 23 sixteen-day periods per year (001, 017, ... 353). There are two types of Filled Land Surface Albedo Products: 1-minute Map Products and coarser resolution Statistical Products.

Map Products, containing spatially complete land surface albedo data, are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DAILY EIGHT DAY MONTHLY (Level-3 Products) | ALBEDO NDVI ECOSYSTEM (Level-3 Ancillary)
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for the developer
Acquiring HDF Datafiles
Anonymous FTP Download
1. Select Product To Download:
Maps
Filled Albedo Maps
(Black Sky or White Sky, organized by wavelength)
Filled Albedo Map Run-Time QA
(organized by wavelength)
MOD43B3 Albedo Map QA
(organized by wavelength)
Statistics
Filled Albedo Map Statistics
(Black Sky or White Sky, organized by resolution)
Filled Albedo Map Statistics By Ecosystem Type
(Black Sky or White Sky, organized by resolution)
Filled Albedo Map Snow Statistics
(Single or Multiyear Stats, by hemisphere or season)
2. Click Go:
Go!
May take up to 30 seconds to be redirected to FTP site

Spatially Complete Sfc. Albedo Datasets

Further information:

Moody, E. G., M. D. King, S. Platnick, C. B. Schaaf, F. Gao, 2005: Spatially complete global spectral surface albedos: Value-added datasets derived from Terra MODIS land products. *IEEE Trans. Geosci. Remote Sens.*, **43**, 144-158.

Moody, E. G., M. D. King, C. B. Schaaf, D. K. Hall, and S. Platnick, 2007: Northern hemisphere five-year average (2000-2004) spectral albedos of surfaces in the presence of snow: Statistics computed from Terra MODIS land products. *Rem. Sens. Env.*, **111**, 337-345.

Moody, E. G., M. D. King, C. B. Schaaf, and S. Platnick, 2008: MODIS-derived spatially complete surface albedo products: Spatial and temporal pixel distribution and zonal averages. *J. Appl. Meteor. Climatol.,* ***47, 2879--2894.***

Extras

MODIS Land Website
(modis-land.gsfc.nasa.gov/)